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Probable Levels of R&D Expenditures in 1990

Forecast and Analysis

This Battelle report is based upon a continuing study of U.S. expenditures for research and development. It was prepared by Drs. Jules J. Duga and W. Halder Fisher of Battelle's Columbus Division. Parts of the data presented here were derived from such sources as the National Science Foundation, the McGraw-Hill surveys, and others.

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PROBABLE LEVELS OF R&D EXPENDITURES IN 1990
SUMMARY OF FINDINGS

1. Battelle forecasts that the total U.S. expenditures for R&D will be $138.7 billion during calendar year 1990. This is an increase of 4.8 percent over the $132.4 billion that the National Science Foundation (NSF) estimates actually will have been spent in 1989.

2. Costs of performing R&D are expected to rise approximately 2.6 percent from 1989 to a 1990 index level of 142.85 (1982 = 100 percent), absorbing a portion of the increased funding. However, this implies a *real* increase in expenditures of approximately 2.14 percent, reaching a new peak in total real funding of R&D (Figure 3).

3. Federal government funding in 1990 is expected to be about $64.9 billion (46.8 percent of total), an increase of $2.24 billion (3.6 percent) from 1989. Performance of R&D by the federal government will represent $15.2 billion (11.0 percent), an increase of $464 million (3.1 percent) over 1989 estimates.

4. Industrial funding in 1990 is expected to be nearly $67.8 billion (48.9 percent of total) representing an increase of $3.7 billion (5.8 percent) over that of 1989. Performance of R&D by industry is expected to rise to $100 billion (72.2 percent of total), an increase of $4.7 billion (4.9 percent over 1989).

5. Estimates of federal government versus industry support for the R&D performed by each of several broad industrial sectors are included in the 1990 forecast. Drawing upon historical trends, the anticipated total performance by the industrial sector has been calculated—first within each of 17 major industrial groups, and then according to whether that performance is supported by federal government or industrial funds. These estimates are shown in Table 4.

6. In 1990, the federal government is expected to support slightly over 70 percent of the aerospace industry's R&D activity, almost two-fifths of electrical machinery/communications, and nearly one-fourth of the R&D in the broadly defined rubber products industries. All other broad manufacturing industry classes are expected to be supported primarily by industry funds with these ratios ranging from 84 percent for the professional and scientific instruments industries, up to 100 percent for the food and beverage, pulp and paper, and textiles industries. Overall, 34 percent of industrial R&D will be federally funded with the remainder funded by industry.

7. Academic and other nonprofit institutions taken together are expected to fund over $5.9 billion of R&D in 1990 (4.3 percent of total) and to perform over $23.3 billion (about 16.8 percent). These figures represent almost negligible increases in the percentage of support and performance over the 1989 NSF estimates. These figures also include the federal support to Federally Funded Research and Development Centers which are managed by individual universities or consortia.

8. Within the nonprofit category, colleges and universities are expected to account for 68.6 percent of the 1990 funding and 84.2 percent of the R&D performance. Both of these figures are comparable with the ratios derived from the 1989 NSF estimates.

9. Historically, the costs of R&D performance have risen steadily in all four categories (federal, industrial, colleges and universities, and other nonprofits), with the rate of increase being driven by overall inflation, a so-called "sophistication" factor, and the general nature of research programs.

10. The trends in real R&D effort (see Figure 3) continue to move upward, as they have over much of the past decade. Since 1977 real R&D effort has increased at a 10-year average rate as high as 3.6 percent, and the projections for 1990 suggest that the 11-year average rate will be slightly smaller (3.1 percent). Battelle estimates that during the next few years real R&D activity will increase at an average annual rate of approximately 2.6 percent, *slightly lower than recent behavior, but maintaining a generally upward trend.*

11. Significant factors that appear to be influencing trends in the support and performance of R&D include:

    (a) Federal government emphasis on defense programs will have a continued influence on total R&D support and the principal industrial performers. These emphases will be felt primarily in the aerospace, electronics, and communications industries, but the rate of growth is expected to show a continued decline and a possible turnaround under the Bush Administration.

    (b) Energy-related R&D programs will continue to experience mixed federal support, with increased funding in basic energy sciences and defense-related energy programs. In addition, health-related R&D will receive a significant boost over previous levels of funding.

(c) University self-funding of R&D is expected to continue to show real increases, partially as a result of industrial "directed programmatic endowment" support of basic and applied research, and a continued support of cooperative research programs.

(d) The Gramm-Rudman-Hollings Act and the so-called "peace" dividend will not have as much impact on R&D as they will on other procurement by the federal government. However, other federal actions and the Bush Administration will influence both federal and industrial support.

12. As a continuing feature, this report provides a preliminary forecast of R&D funding levels in 1991. Indications are that total U.S. expenditures for R&D in 1991 will be $143.5 billion (uncorrected for inflation).

13. The types of statistics and surveys—even with their inherent inaccuracies—are sufficient for broad analyses of U.S. R&D trends; however, it is shown that much more detailed work will be required if R&D analyses are to be more useful for defining competitive postures, both for individual industries and for the nation as a whole.

ANALYSIS AND FORECAST

Since research and development (R&D)* and the applications of technology are our prime concerns, Battelle is interested both in forecasting R&D expenditures and in assessing the cumulative results of R&D activities—technological, economic, and social. Accordingly, Battelle has carried on a continuing study into the forces affecting R&D activities and sources of support. Among the tangible products of this research has been a series of annual analyses and forecasts of R&D expenditures. This report represents the latest in that series.

The content of this report has evolved over the years in an attempt to supply information Battelle considers useful to the R&D community, but not adequately supplied by two well-known and respected series of reports: the National Science Foundation's *National Patterns of Science and Technology Resources* and the DRI/McGraw-Hill *Annual Survey of Business Plans for R&D.*

In earlier years, NSF *Patterns* was published during the first half of each year (usually in April) and had included a forecast of that same full year's R&D expenditures by source of funds and by performer. However, since the fiscal year now begins in October, *Patterns* had contained both the preliminary data for the closing fiscal year and estimates for the two preceding years. Recently, the publication of *Patterns* has been delayed until late in the calendar year, and it contains better estimates of the R&D funding and performance for that same year.

Budget restraints and employment freezes at NSF have taken their toll on the *Patterns* report and the supporting activities throughout the NSF Division of Science Resource Studies. The effects of these cutbacks have been felt not only by continuing private-sector users of NSF data but also by policy makers and analysts within the federal government. As an additional complication, NSF data have always had a degree of uncertainty, especially as they relate to recent years' histories. Each year, the NSF data on previous years (sometimes as far back as 10 years) have been subject to corrections. For example, the 1984 data reported in 1989 are different from the 1984 data that were published in 1988. These adjustments thus present problems in consistency between forecasts made in different years. The lack of background data and their interpretation can only have a negative impact on those agencies concerned with the strength of the U.S. R&D effort and the policy measures that need to be taken in order to assure competitive postures. More will be said of this in later sections of this Forecast.*

The McGraw-Hill surveys (usually published at about the same time as the earlier issues of *Patterns*) make forecasts—the 1989 Survey (published in June) made forecasts for 1989 and 1991—but are confined to the overall performance of broad industrial sectors, some of which are not well defined and delineated, and do not separate federal government from industrial funding. These surveys, coupled with the "R&D Scoreboard" published in mid-year by *Business Week*, are instructive to the extent that they provide generalized patterns and trends. However, as will also be shown in later discussions (see the Section titled "The Need for Better Data"), they fall far short of providing a complete tool for detailed analysis, evaluation, or planning.

The Battelle report, usually published in December or shortly after the beginning of the subject year, has been intended to fill the remaining void, by emphasizing the coming year (in this case, 1990) and industrially funded R&D. Other relevant inputs, gleaned from many sources, have also been included. While this present Forecast addresses some gaps in information, it also shares some of the shortcomings of other related documents.

*The National Science Foundation's definitions of R&D are given in the Technical Appendix to this report.

*See special note, added in press, which appears at the end of this report.

Since the issuance of the 1980 Forecast, we have included a forecast of industrial R&D expenditures according to broad industry class, along with the estimated distribution of those funds between industrial and federal sources. This added feature provides the background necessary for understanding the way federal policy can affect industrial innovation, spur industrial support of its own R&D efforts, and enhance the long-term international competitiveness of U.S. industry. Although related aspects of productivity, training and employment needs, tax incentives, balance of payments, and other concerns are not predictable, we anticipate that continued analysis of this subject—as well as detailed studies of line-of-business or line-of-activity R&D—will help identify both the promises and the problems associated with industrial responses to future opportunities.

Continuing the practice initiated in the 1984 Forecast, we present estimates which cover a two-year forecast to 1991.

Historical Trends in R&D Funding and Performance

Although the NSF data series began in 1953, we begin our analysis with 1960 data. Even that year represents ancient history so far as the forces currently affecting R&D are concerned. The NSF data from 1960 through 1989 are shown in Table 1.

In 1960, NSF surveys indicated that approximately 64.6 percent of all R&D-supportive funds were provided by the federal government; 33.4 percent were provided by industry; and 1 percent each came from the academic community and from other nonprofit organizations.

Between then and 1984, federal funding rose to 66.5 percent in 1964, slowly declined to 46.0 percent in 1982, rose slightly to 48.3 percent in 1986, and slowly declined since then.* Over that same period, industrial funding declined to 31.2 percent in 1964 and rose to 50.5 percent in 1982, with a small decline thereafter and a slow rise since 1986. Since 1964, the percentage of total funding by colleges and universities rose steadily to a value between 2.0 and 2.3 percent of total funding. This level of funding remained constant for nearly a decade and a half, and then suddenly increased to 2.8 percent in recent years. Other nonprofit funding reached a high of approximately 1.6 percent of the total (in 1978) but has exhibited a slow decline in the past decade. The apparent growth in college and university funding is partially ascribable to the more detailed bookkeeping methods that are used to account for this sector's sources of funds.

Through 1982, trends showed a continued increase in industrial funding as a percent of total funding, with a corresponding decrease in the proportion of federal-sector funding. Over the past four years, however, the relative contributions by industry and the federal government have remained essentially constant. This is largely due to significant increases in defense spending, industrial response to a healthier economy, and other initiatives (see the later discussions on the role of industry).

Although the federal government had been the major *source* of R&D funds from 1953 through 1979, industry became the dominant R&D funder over the period 1980–1989, with the exception of 1986–88. Industry is by far the major *performer* of R&D. Federal performance of R&D rose from 12.8 percent in 1960 to 16.1 percent in 1972. It has been decreasing since that year and has fluctuated around the 12 percent mark since 1980. Industrial performance reached a high point of 79 percent in 1957 and drifted steadily downward to a low of 68.6 percent in the early 1970s. More recent trends suggest a slow increase in the proportion of industrial performance, which has risen to over 73 percent and has maintained nearly that share over the past eight years albeit with slight recent declines.

While the academic community's performance varied between 6 and 8 percent before 1960, there has been a slow but steady increase in the percentage of R&D performed in this sector, with recent levels reaching 14 percent. This total includes the R&D performed at the university-managed Federally Funded Research & Development Centers (FFRDCs). Since the early 1980s, this sector's share of performance had been in slight decline, although there has been a reversal of this trend in the most recent six years. Such a reversal has resulted in part from industrial initiatives (see later). For most of the 1960–80 period, other nonprofit organizations increased their share of performance of R&D from 2 to about 3.6 percent of the total, again with recent declines in that share.

It should be noted that federal funding supports research performed by all sectors. Currently, almost one-fourth of federal R&D funding supports intramural R&D; slightly over one-half supports industry; a little more than one-fifth supports colleges and universities (through direct grants and contracts, as well as through the FFRDCs); and the rest, slightly less than 4 percent, supports other non-

*Note that NSF data for 1988 and 1989 are "estimated." However, comparisons among the series of *Patterns* reports reveal that adjustments are made on earlier years' figures, with some adjustments carrying back several years. Thus, many of our calculations that are dependent upon long-term figures will vary from one year to the next.

TABLE 1. SOURCES OF R&D FUNDS AND PERFORMERS OF R&D, UNITED STATES, CALENDAR YEARS 1960–1989

(Millions of Current Dollars)

		Sources of Funds				Performance [a]			
Year	Total R&D	Federal Gov't	Industry	Colleges and Universities [b]	Other Nonprofit [c]	Federal Gov't	Industry	Colleges and Universities [b]	Other Nonprofit [c]
1960	13,523	8,738	4,516	149	120	1,726	10,509	1,006	282
1961	14,316	9,250	4,757	165	144	1,874	10,908	1,173	361
1962	15,394	9,911	5,123	185	175	2,098	11,464	1,374	458
1963	17,059	11,204	5,456	207	192	2,279	12,630	1,611	539
1964	18,854	12,537	5,887	235	195	2,838	13,512	1,904	600
1965	20,044	13,012	6,548	267	217	3,093	14,185	2,103	663
1966	21,846	13,968	7,328	304	246	3,220	15,548	2,345	733
1967	23,146	14,395	8,142	345	264	3,396	16,385	2,594	771
1968	24,605	14,928	9,005	390	282	3,494	17,429	2,868	814
1969	25,631	14,895	10,010	420	306	3,503	18,308	2,950	870
1970	26,134	14,892	10,444	461	337	4,079	18,067	3,072	916
1971	26,676	14,964	10,822	529	361	4,228	18,320	3,216	912
1972	28,477	15,808	11,710	574	385	4,590	19,552	3,383	952
1973	30,718	16,399	13,293	613	413	4,762	21,249	3,701	1,006
1974	32,864	16,850	14,878	677	459	4,911	22,887	3,888	1,178
1975	35,213	18,109	15,820	749	535	5,354	24,187	4,396	1,276
1976	39,018	19,914	17,694	810	600	5,769	26,997	4,876	1,376
1977	42,783	21,594	19,629	888	672	6,012	29,825	5,451	1,495
1978	48,129	23,876	22,450	1,037	766	6,811	33,304	6,342	1,672
1979	54,933	26,815	26,082	1,198	838	7,417	38,226	7,296	1,994
1980	62,594	29,453	30,914	1,326	901	7,632	44,505	8,307	2,150
1981	71,836	33,374	35,946	1,555	961	8,425	51,810	9,301	2,300
1982	79,364	36,512	40,101	1,735	1,016	9,141	57,995	9,803	2,425
1983	87,280	40,691	43,524	1,936	1,129	10,582	63,403	10,620	2,675
1984	97,793	45,377	49,107	2,107	1,202	11,572	71,470	11,741	3,010
1985	107,757	51,668	52,358	2,377	1,354	12,945	78,269	13,223	3,320
1986	112,497	54,331	53,950	2,789	1,427	13,535	80,631	14,826	3,505
1987	118,782	57,291	56,722	3,145	1,624	13,413	85,500	16,284	3,585
1988	126,115	60,500	60,430	3,470	1,715	14,500	90,600	17,400	3,615
1989[d]	132,350	62,700	64,035	3,800	1,815	14,750	95,350	18,550	3,700

Source: National Science Foundation

(a) The R&D performance of Associated Federally Funded Research & Development Centers (some administered by industry, some by colleges and universities, and some by other nonprofit organizations) has been combined with that of the administering institutions.

(b) As sources of funds, these include state and local government funding.

(c) All other nonprofit institutions.

(d) Preliminary estimates by NSF.

profit organizations. Industry absorbs almost all of its own funding, either intramurally or by contracting with other industrial performers. Its contracts and grants to colleges and universities exceed those to other nonprofit institutions by nearly 80 percent. Other nonprofits finance both themselves and academic institutions about equally, while colleges and universities absorb all the funds they originate.

In Table 1 we summarize the latest NSF time series on the sources of R&D funding and the volumes of R&D performance. During the interval since 1960, total R&D dollars (not adjusted for inflation) have increased almost tenfold. Federal funding has multiplied by a factor of 7.2 and federal performance has increased by a factor of over 8.5. In terms of constant dollars, total R&D expenditures doubled from 1960 to 1989, and federal performance has increased by slightly over 26 percent (see Table 6).

Also noteworthy is the high ratio of academic performance to academic funding. In the later years of this period, colleges and universities have provided about one-sixth of the total support for their own R&D activity, with much of the remainder (about 90 percent) coming primarily from the federal government. In recent years, this ratio has tended

to decrease, not only as a result of some reduction in selected federal programs but also because of an increase in academic funding. As suggested earlier, this latter is largely a "bookkeeping" artifact created by the manner in which university funds are ascribed to the universities, rather than to the ultimate original sources. More will be said about this in later sections of the Forecast.

Beginning in 1968, there was a distinct change in the rate of growth in R&D, triggered by a leveling in current-dollar federal funding. This phase of the recent past seems to have ended with 1971, when current-dollar expenditures resumed an accelerating growth trend more nearly like that before 1968. As anticipated in the last three years' Forecasts, there is a continued growth of total real R&D support, although the rate of growth has slowed. Present trends even suggest that the total real R&D support could go through a short-term reversal. Whether this will happen will depend upon a number of factors to be elaborated upon later in this report.

The continuing transition in the support and performance of R&D, to which we referred in earlier Forecasts, has had a significant impact on the patterns within the overall R&D enterprise. In addition to changes in energy and social service R&D programs, there have been changes in the structure of federally supported R&D. In particular, the budgets for basic research—much of which is directed ultimately toward defense applications—have shown a steady increase, growing at a rate of about 8 percent per year (in current dollars). However, the portion of federal R&D dollars directed toward truly basic research appears to have been declining in recent years.*

The changing emphasis by the federal government has been translated to the encouragement of selected R&D programs within the private sector and the determination to let the marketplace decide the most fruitful areas for private investment. Federal initiatives that indirectly affect industrial R&D, to be discussed in more detail later, include tax incentives, the encouragement of collaborative research within sets of competing companies, and the manner in which tax laws encourage mergers and acquisitions.

Presently, the strongest federal action, as we shall see in later sections of this forecast and analysis, continues to be in areas of fundamental concern to the central government, as perceived by the Administration: (1) national defense; (2) technological competition from our trading partners; (3) health; and (4) the environment for economic growth. The extent to which federal actions can influence these areas will continue to be dependent upon a number of different factors, including the major developments in Eastern Europe, the decline in international tensions, and the pervasive question of the massive national debt.

*One must use caution, however, in attempting to draw too many conclusions based upon the most readily available statistics. Two problems arise: (1) the demarkation between "basic research" and "applied research," as well as that between "applied research" and "development," is not uniformly applied; and (2) the actual detailed surveys are not sufficiently accurate, reproducible, or recent to provide much confidence in the details.

Forecast for 1990

During calendar year 1990, Battelle expects the total current dollar volume of R&D activity to be higher than the 1989 level estimated by NSF. A comparison of Battelle's 1990 forecast with the last available NSF estimates for 1989 is shown in Table 2. The 1990 forecast is shown in its historical setting in Table 1 and Figure 1.

Referring to Table 2, we estimate the total calendar year 1990 R&D volume to be $138.7 billion, a 4.79 per-

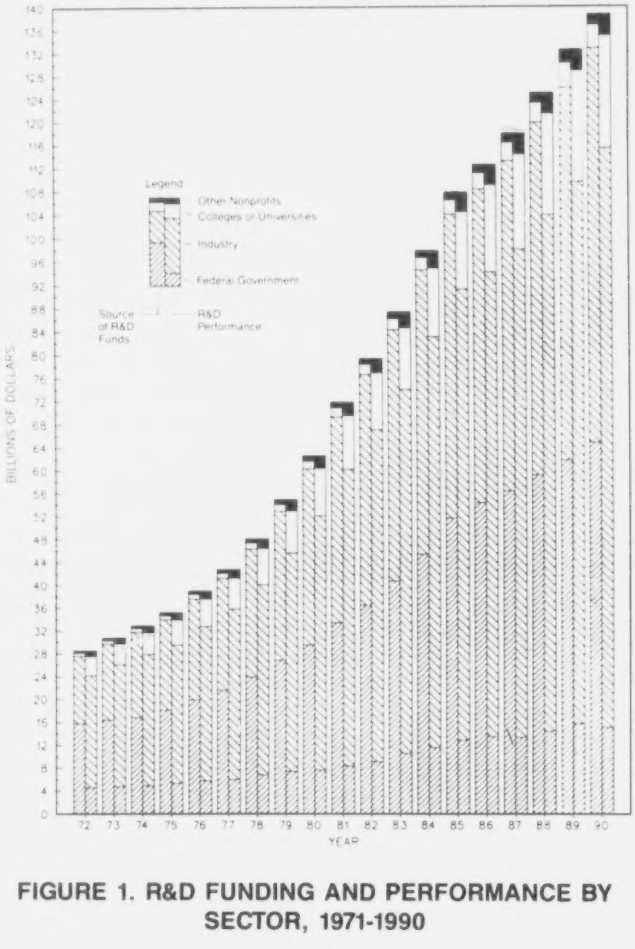


FIGURE 1. R&D FUNDING AND PERFORMANCE BY SECTOR, 1971-1990

TABLE 2. ESTIMATED R&D EXPENDITURES BY SOURCE OF FUNDS AND BY PERFORMERS, U.S. CALENDAR YEARS 1989 AND 1990

(Millions of Current Dollars)

Source of Funds	Performer				Source Totals	
	Federal Government	Industry	Colleges and Universities	Other Nonprofit	Dollars	Percent of All Funds
1989 NSF ESTIMATES						
Federal Government	14,750	32,750	12,900	2,300	62,700	47.37
Industry	—	62,600	920	515	64,035	48.38
Colleges & Universities	—	—	3,800	—	3,800	2.87
Other Nonprofit	—	—	930	885	1,815	1.37
Performer Dollars	14,750	95,350	18,550	3,700	132,350	100
Totals Percent	11.14	72.04	14.02	2.80		
1990 BATTELLE FORECAST						
Federal Government	15,214	33,859	13,620	2,250	64,942	46.83
Industry	—	66,207	994	552	67,753	48.85
Colleges & Universities	—	—	4,064	—	4,064	2.93
Other Nonprofit	—	—	981	878	1,859	1.34
Performer Dollars	15,214	100,066	19,659	3,696	138,684	100
Totals Percent	10.97	72.15	14.18	2.67		
PERCENTAGE INCREASES OVER 1989 ESTIMATES						
Federal Government	3.14	3.39	5.58	(2.17)	3.58	
Industry	—	5.76	8.07	7.12	5.81	
Colleges & Universities	—	—	6.95	—	6.95	
Other Nonprofit	—	—	5.52	(0.79)	2.44	
Performer Dollars	3.14	4.95	5.98	(0.10)	4.79	

cent increase over the NSF estimates for 1989.* It is expected that part of this increase will be absorbed by continued inflation (which we estimate to be only 2.59 percent from 1989 to 1990 for R&D).

In connection with this forecast, several important factors must be recognized. First, the total current-dollar projected increase includes an inflation factor that depends primarily on the inflation rate as it applies to R&D alone. As will be noted in the discussion of the Cost of Research Index, this inflation factor is fundamentally different from that associated with the more familiar Consumer Price Index.

In addition, it is apparent that concerns over the federal debt have influenced the appropriations bills for the 1990 federal budget. Furthermore, since part of the calendar year 1990 will come during the next fiscal year (1991), the budget process throughout this current calendar year will have a continuing effect on total expenditures. Finally, industrial support for R&D will continue to be affected by previous years' sales and earnings and should be expected to increase at a moderate rate.

In using Table 2, the reader should keep clearly in mind all the distinctions made by the table headings. For instance, in the *column* headed "Industry," we see that the total amount of R&D expected to be performed by industry in 1990 will be $100 billion. Of this, $33.8 billion will be funded by federal agencies, and $66.2 billion by industry. On the other hand, the *row* headed "Industry" indicates that industrial sources of funds are expected to support about $67.7 billion of R&D. Of this, $66.2 billion will be performed by industry, nearly $1 billion by colleges and universities, and $552 million by other nonprofit organizations. Included within the "Industry/Industry diagonal" element is that research and development which is sup-

*These NSF estimates are presented here as reported in "National Patterns of R&D Resources: 1989," NSF Report 89-308, January, 1989.

ported by one industrial organization and performed by another.

Continued inflation is expected to characterize 1990, although the rate, as experienced in R&D, has been declining for the past few years. In addition, there are many intangibles that favor continued increases in support, including the perception on the part of both federal and industrial decision-makers that R&D is vital to long-term economic health. The NSF estimated that current dollar total R&D activity rose by 4.9 percent from 1988 to 1989. We project a slightly smaller increase, 4.79 percent, from 1989 to 1990. As will be shown in connection with the Cost of R&D Index, not all of this increase is expected to be absorbed by inflation.

With respect to the *composition* of R&D activity, the expected pattern continues to be one of year-to-year stability or very slow change. Expected to provide the major impetus for change are defense-, science-, and technology-based problems; considerations of economic development and the federal budget deficit; and foreign competition. It is also important to note that the proportionate composition of both funding and performance will change very little. The federal government will account for 46.8 percent of the total funding, as compared with 48.9 percent from industry. Industry will account for almost three-fourths of total performance. These two distributions for 1990 are summarized in Figure 2.

The Role of Federal Agencies

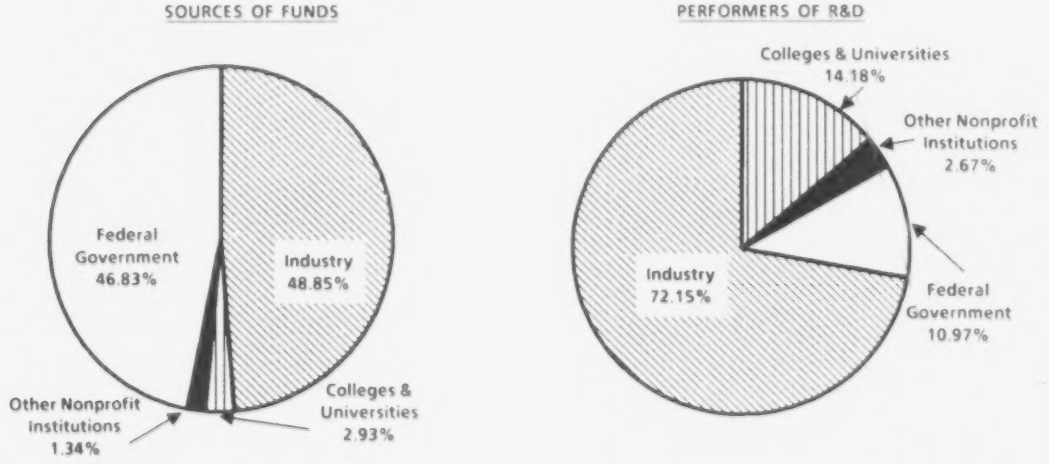
Since federal funding was historically the major source of R&D support (although it has been outdistanced by industry during much of the '80s), the forces likely to affect federal R&D budgets in Fiscal Year 1990 and beyond are important in the present Forecast. The federal budget for Fiscal Year 1990, which began on October 1, 1989, continues the emphasis of the Reagan Administration. However, major changes in international affairs may have a greater influence in 1990 and subsequent years.

The decline in the rate of growth of federal support had been suggested in the last three years' Forecasts and is occurring, although for a mixed set of reasons. Earlier predictions from many quarters regarding the impact of the Gramm-Rudman-Hollings Act have not been fulfilled. R&D seems to have fared well both in the Administration and in Congress.

Battelle projects that federal funding in calendar year 1990 will likely reach a level of $64.9 billion. This figure is based upon: (1) recent trends in federal budgeting, as reflected in NSF data series on R&D funding; (2) the relationship between federal funding and federal obligations; (3) the fact that three calendar quarters' funding will be determined by the FY 1990 appropriation; and (4) the modification of selected mission agency activities.*

*Note that this estimate applies only to spending for the *performance* of R&D, and does not include any spending for R&D *facilities*.

The total forecast by Battelle is $138.7 billion.
Distribution shown here is by source and performance.



Source: Battelle

FIGURE 2. R&D EXPENDITURES IN THE U.S., CALENDAR YEAR 1990

The R&D-Minded Agencies

The big-money agencies in terms of total 1990 federal R&D funding will include the Department of Defense (DoD), the Department of Health and Human Services (HHS), the National Aeronautics and Space Administration (NASA), and the Department of Energy (DOE). Among the smaller agencies, the important suppliers of funds for extramural R&D are the NSF, the Department of Agriculture (DOA), the Environmental Protection Agency (EPA), the Department of the Interior (DOI), the Department of Transportation (DOT), and the Department of Commerce (DOC). Estimated percentage shares for conducting R&D in the early proposed budgets for FY 1990, and comparative estimates of the FY 1988 and FY 1989 plans, are:

	1988 Actual Authority	1989 Estimated Authority	1990 Estimated Authority
DoD	63.77	61.72	61.62
HHS	11.99	12.51	12.16
NASA	7.24	8.56	10.24
DOE	8.53	8.79	8.07
NSF	2.59	2.69	2.77
DOA	1.72	1.70	1.54
EPA	0.60	0.63	0.62
DOI	0.71	0.69	0.57
DOT	0.51	0.51	0.49
DOC	0.68	0.67	0.47
All Others	1.67	1.54	1.44

It is obvious from this listing that DoD continues to dominate the federal scene, accounting single-handedly for about three-fifths of the R&D budget. The Big Four (DoD, NASA, DOE, and HHS) account for over 92 percent of anticipated federal R&D expenditures, although the distributions within these four have changed slightly over the recent past (and are expected to do so in the future). The next six largest R&D-supporting agencies account for only 6.46 percent, and all others combined account for approximately 1.44 percent.

The continued increase in defense-related R&D derives from the development and acquisition of more advanced major weapons systems, and the Administration's commitment to highly sophisticated space-deployed defense approaches.

The principal increases in DoD budget are driven by R&D in advanced technology development, particularly that supported by defense-wide agencies. In addition, R&D on tactical programs, supported by all of the major services, is expected to contribute to the total DoD expansion.

The resurgence in NASA programs is largely influenced by space transportation systems research, much of which will be directed toward the space station, designed to serve as a permanent manned laboratory facility. In addition, continued and expanded effort will be directed to advanced safety systems and to effort to enhance the commercial utilization of space.

Very few federal agencies confine their R&D efforts to functional areas that are suggested by the agency's title. For example, the Department of Energy supports work related to defense, environment, and basic science (especially in materials). Similarly, NASA conducts research programs aimed at air transportation, and the area of natural resources and environment is supported by EPA, DOA, DOI, DOC, and even DoD. Redistribution of the federal R&D spending in terms of broad functional area results in a different picture of the federal budget, as follows:

Federal Funding, by Broad Functional Areas: (millions of current dollars)

	1988 Actual Authority	1989 Estimated Authority	1990 Estimated Authority
Defense	40,098	40,573	44,295
Health	7,065	7,708	8,228
Space Sci/Tech.	3,683	4,589	6,146
General Science	2,161	2,379	2,652
Energy	2,127	2,428	2,333
Nat. Res. & Env.	1,161	1,210	1,141
Transportation	897	1,020	1,129
Agriculture	882	910	901
Educ./Training/ Emp.	285	344	347
Veterans Benefits	195	212	199
International Affairs	224	141	169
Commerce/ Housing C	122	134	132
Comm./Reg. Dev.	108	77	79
Adm. of Justice	51	46	41
Income security	23	27	25
General government	17	15	17

Although the final figures are not available, the trends are important. Review of these data reveals that the major increases in funding authority are being requested in space

science and technology, international affairs, general government, general science, and transportation. Along with defense and health, these functional areas will have R&D budget increases which outpace inflation.

From 1972 to 1979, year-to-year changes in R&D budgets favored civilian programs over defense/space. Beginning with 1980, emphasis shifted back toward defense and space, especially the former.* Throughout the 1970s, the funding of energy-related R&D generally grew by larger increments than that of space or of most other civilian programs. When expressed as a fraction of total federal R&D support, a significant bulge in non-defense-related energy research began in 1973–74, reached a peak during the 1979–80 period, and has since declined. By 1988, the proportion of federally supported energy R&D had dropped to its 1973 value. It is expected that federally supported energy-related research and demonstration programs will continue to decline, except for that portion which supports direct national defense interests and general science activities. As has been the case in the recent past, energy programs which involve short-term and/or low-risk R&D will probably have to be financed by private industry.

Factors Affecting Future Federal Support

There appears to be a continuing effort on the part of the federal government to increase funding of R&D, in terms of both support to basic national needs and the broadening of the technological base on which future growth is predicated. National security continues to be a principal driving force in furthering R&D spending. Economic growth, founded upon both basic and applied research, is expected to remain as an objective which requires direct and indirect federal support, with greater emphasis on the latter.

Federal efforts in energy research will continue to serve basic research that is inappropriate for industrial support, or that represents such long-term investments that no industrial applications are expected in the near future. With the decision on the Superconducting Supercollider (SSC) having been made, additional emphasis on high-energy basic physics research may be forthcoming. There is no doubt that, all else being equal, this award can have significant impact upon R&D. However, all else is *not* expected to be equal, with concerns for balanced budgets and government cutbacks tempering the original enthusiasm. Much of the near-term support for the construction and operation of the SSC may be sacrificed during the forthcoming federal budgets, and these in turn will be influenced by the new Bush Administration. Effort will continue on the design parameters and on other pre-construction aspects of the project, although the budget requests already show evidence of a reduction in R&D effort.

There are indications that industrial support will be growing in biological sciences (as is evidenced by continued industrial funding at universities); and the federal government will continue to commit substantial resources toward this and allied fields. Budget-trimming efforts, especially as they apply to health and agriculture, have been largely cosmetic in recent years. They generally have been offset by Congressional action to reinstate various programs in such areas.

Several years ago, there was concern that federal funding of R&D might shift from extramural contract/grant support to intramural research performance utilizing the capabilities of the extensive federal laboratories and the Federally Funded Research and Development Centers. There is little evidence that any shift from extramural to intramural programs had been made through 1988. Furthermore, we anticipate that any such changes would be relatively small, and slow in coming. The overall shares in federal funding of both the truly intramural and the university-operated FFRDCs have been declining, as shown below:

Percentage of Federal Funds Expended

Year	Federal Laboratories	University-Operated FFRDCs
1979	27.7	7.2
1980	25.9	7.6
1981	25.2	7.4
1982	25.0	6.8
1983	26.0	6.7
1984	25.5	6.9
1985	25.1	6.8
1986	24.9	7.2
1987	23.4	7.3
1988	24.0	7.3
1989	23.5	7.4

Throughout the next few years, we expect that a greater emphasis will be given to the translation of federally generated and held technology into applications in the private

*Although the share of total federal R&D in support of space research may appear to have been in decline, it is important to note that early NASA funding was almost *totally* termed as "research." When the shuttle was deemed to be an operational vehicle, the total support of the shuttle program was no longer classified as research.

sector. Much of this effort has taken place (especially in DOE laboratories). However the emphasis in DoD laboratories has not been so pervasive.

Given the potential for the so-called "second use," to which we referred later, the possible applications of materials and manufacturing technology, the verbal commitment to enhancing international competitiveness, and the effort to enhance local importance of DoD facilities, the federal intramural laboratories may be taking on a greater importance as arms of industry. Additional federal funds might be made available for the conduct of the technology adaptation and transfer programs that will be required. We do not, however, expect this to be a major effort that is concentrated in the laboratories themselves; the so-called "fourth category of research" will probably be funded across all performing sectors.

The federal laboratory/industry interface is expected to be strengthened within the next few years. Already, state and local governments are establishing programs that will help to accelerate the diffusion, application, and commercialization of technology that had been developed in federal laboratories. The effort to promote this type of interaction goes well beyond the initiatives suggested in the legislation that has promoted technology transfer or the establishment of networks for problem-solving. In particular, state governments have begun to formalize procedures whereby linkages between federal laboratories and the private sector, drawing from a knowledge of industrial needs, research-in-progress in federal laboratories, and an analysis of the potentials for "second- or alternative-use" applications.

Within this context, it is appropriate to suggest that R&D programs could be viewed as being partitioned into *four*, rather than the classical three, categories: basic, applied, development, and transitional, with the latter applying to efforts at implementing government-developed technology for nonfederal purposes. It is doubtful whether, over the next few years, any statistics will or can be provided to estimate the amount of effort directly related to the activity. However, it is instructive to note that much of the translational effort will be ongoing.

One cannot overlook the impact that federally sponsored R&D has had on the national economy. Major government-sponsored programs in defense, space, health, energy, and other areas have assisted in fulfilling the fundamental responsibilities of the federal government, and they have also spurred development in almost all sectors of U.S. industry. The implementation of research results—many of which were originally supported by federal funds—has created an economy with strength and versatility to match any found in the world. The extent to which federally supported research can be and has been used is influenced by a vast array of factors, such as the restrictions placed on the use of intellectual property, the complexity of tax laws, and the demands and expectations which are inherent in a free-market, public-ownership economy.

As federal efforts are made to enhance the competitiveness of U.S. industry, it is appropriate to point out that the federal government cannot do it all, and should not be expected to do so. The responsibilities for increasing productivity, for diversifying the products of manufacturing, and for meeting the challenges by other countries rest equally on all public and private sectors. When faced with an interlocking worldwide economy in which developing countries are expanding their own presence in the market, it is incumbent on the federal government to (1) maintain a posture of continued R&D investment, creating an improved stockpile of usable technological outputs and (2) provide an atmosphere wherein the fruits of these investments can be more readily adopted and adapted for commercial benefit.

The "translational" research noted above is not expected to be an easy undertaking. Throughout the past three decades, a number of different approaches have been taken to ensure that the fruits of federal investment in science and technology would have direct impacts on private business. The overall movement has been characterized by fits and starts, great public relations efforts, technology transfer fairs, and the "selling" of the national store of technology. Unfortunately, most early efforts failed to take into account the fact that "answers searching for questions" has not been an effective marketing or promotional tool.

In addition to the technical effort that would be required to translate defense and space research into a wide range of applications, several other stumbling blocks have been encountered. The maze of federal regulations and the difficulties of finding and interacting with the appropriate technologists have been found to be formidable barriers. Those companies who were not already tuned into the federal bureaucracy and culture experienced considerable frustration. In addition, the providers of the technologies were of little help when faced with industrial concerns regarding mass production and finite budgets.

As innovative means are defined for easing the translation of research into second-use applications, some of the most important contributions will be made by those who have a sensitivity to the needs and constraints of the private industry market, and a sense of what is required in order to bring something to market.

In previous years' discussions, there has been a continuing emphasis on the fact that the U.S. R&D enterprise is fully capable of producing the types of knowledge that can be applied to almost any area of human endeavor. What has been a source of some frustration, however, has been the apparent reluctance of industry to adopt and adapt and implement the benefits of R&D.

There is evidence that this will be changing over the next few years, with the impetus coming from industry and from both state and federal governments. To be sure, one must be continually mindful of the fact that it will still not be technology alone that will drive the decision-making process. At the same time, it is instructive to consider the following perceptions:

The federal government has been promoting technology transfer for a number of years, starting with the Stevenson-Wydler Act of 1980. This has been supplemented by various technology transfer acts that have strengthened the intent and have opened the door for greater incentives (both to the individuals and to the laboratories). As the major source of federal R&D, the Department of Defense has been encouraging their major laboratories to promote technology transfer in response to the overall federal directives.

There is continuing emphasis on the fact that the federal government laboratories represent a collection of technologies, expertise, ideas, and facilities that could be of significant use to the private sector. Initiatives have been undertaken to establish more substantive cooperation between the federal labs and the non-federal users of technology. The National Institute of Standard and Technology has instituted a cooperative program in biotechnology, supported and encouraged by the State of Maryland.

The Wright-Patterson Air Force Base has, in cooperation with the State of Ohio, started the Ohio Advanced Technology Center, an operation designed to accelerate the development and application of technology in the private sector. Other states have established specialized centers which were set up to provide contract research services to local federal laboratories and, it is anticipated, to provide a linkage between the federal and private sectors.

In almost all of these cases, the concept of technology transfer is operating for the benefit of existing local businesses (i.e., within the given state) as well as for a means of creating *new* businesses, a move toward economic development.

The above-mentioned pressure and initiatives have created a milieu in which it is in the best interests of the *suppliers* of technology to "justify their existence" beyond the direct application to their primary mission. This posture has been taken advantage of in terms of the initiatives that we referred to above. This will, most likely be a model for future involvement, for future cooperation between the technologists of the government labs and the technology users outside their primary mission agencies.

Further thought has to be given to the issue of availability of technology—what has changed with the new Technology Transfer laws?—wasn't it always available anyhow, but with some restrictions about exclusive use? Will the federal suppliers appreciate the types of restrictions that are faced in the real business world? Will they be able to adjust to a different set of priorities, a different reward system, and an appreciation of the finite nature of industrial resources? To the extent that federal laboratories—along with the properly developed and business-sensitive transfer activities—can serve to spur U.S. industry, the resource may be of incalculable benefit over the next several decades.

The opening up of the federal laboratories is not a panacea. It is a significant step in the right direction. The effort by state or local governments is not significantly different from other initiatives that they have taken, including seed funds for technology development, the fostering of industry/university liaisons, and the establishment of other incentives and institutions. Perhaps a coupling of needs and actions on the part of the various levels of government will provide the type of environment within which existing industry can improve and new industry can be developed.

The Role of Industry

NSF data indicate that during the period 1980–1989, industrial support of R&D was greater than federal support, although the roles were reversed in 1986 and 1987. Battelle projects that industrial funding in 1990 will again exceed federal funding. As has always been the case, industry will be by far the predominant R&D performer.

For 1989, the NSF has estimated that industry provided almost 48.4 percent of total funding and performed over 72 percent of all R&D work (see Table 2). Battelle's forecast for 1990 changes these shares almost imperceptibly to almost 48.9 and 72.2 percent, respectively.

The NSF data base indicates that industry has been the second-fastest growing sector. Table 3 compares sectoral growth rates for the nine-year interval 1980–1989. It is of particular interest that, as a source of funds, colleges and universities have grown quite significantly. The rapid increase in university funding relates to the manner in which R&D statistics are collected and accounted for.

Battelle projects considerable differences among the 1989–90 sectoral growth rates. Total R&D expenditures are expected to grow by 4.79 percent; industrial funding and performance are expected to increase by 5.8 and 4.95 percent, respectively.

Industrial funding is expected to rise from an NSF estimated level of almost $64 billion in 1989 to $67.8 billion in 1990. Industrial performance will rise from $95.4 billion to $100 billion. Note that the increases in both funding and performance by industry are smaller than in previous years, as had been anticipated in the 1989 Battelle forecast.

Industrial research, as it applies to the accomplishment of industrial and governmental objectives, is both a means to an end and an end in itself. While the continuing profit motive in a competitive marketplace spurs R&D for individual industry's benefit, so also does the industrial system provide a mechanism for the execution of programs of high national priority. In view of (1) the continuing emphasis on innovation; (2) the application of advanced control technology to mature industries; and (3) continued tax incentives for industrial R&D, Battelle's 1990 forecast continues a new area of analysis, namely, the comparative federal and industrial funding of R&D in major groups of industries.

Using data derived both from NSF sources and from interpolation or extrapolation of the McGraw-Hill surveys, we have estimated the degrees to which industrial and federal funds will support industry R&D performance (see Table 4).

This distribution between federal and industrial funds is, unfortunately, somewhat misleading because it does not address the more critical question of support for R&D among different lines of business. With R&D expenditures grouped according to major Standard Industrial Classification (SIC) codes, it is not possible to distinguish, for example, electronics research performed by a well-known electronics company from that performed by a subsidiary of a major company whose principal product line (and SIC code) falls into an entirely different category. Conversely, this determination does not isolate, for example, research in chemicals which is performed within the rubber or petroleum industries.

More specific information on the R&D expenditures within industry is extremely difficult to collect and assess, especially in those cases where (1) individual companies are engaged in a variety of research programs to support different lines of business, or (2) companies' R&D is diversified among an array of products and processes within the same line of business.

The extension to the case where both industrial and federal moneys are involved is similarly difficult. Detailed data are available relative to government support of R&D by industry and by area of research. However, the comparison with expenditures of industries' own funds cannot be pursued without dissecting specific industrial R&D budgets.

These latter are, of course, almost always considered as confidential and proprietary information. Over the past few years, Battelle programs have been directed toward analyzing R&D within broad industrial classes, and thereby providing specialized information which assists in the R&D planning, management, and assessment activities of the cooperating industries. It will be quite some time, however, before sufficient detail is collected for a large number of R&D-intensive industries, and for a more nearly accurate picture of the government/industry split—with all its implications—to emerge. More will be said of this in the section on Improvements in Information Resources.

An additional caveat should be noted relative to the ready availability of R&D data. A most convenient source of data on R&D investment is the annual *Business Week* Scoreboard, usually published near the middle of the calendar year. The Scoreboard provides compilations of total R&D data for the major publicly held corporations, along with associated trends and ratios. While these data lend insights into broad patterns of support, they do not include information on privately held and/or small businesses. It is generally held that these latter firms represent a most important element in the areas of applied research, commercialization, and new-job formation.

The difficulties in estimating and forecasting R&D performance by industry are compounded by the fact that the

TABLE 3. SECTORAL GROWTH RATES IN FUNDING AND PERFORMING R&D, 1980–1989

	1980 = 100.0%		
Sector	Source	Performer	Ratio s/p
Total United States	211.4	211.4	1.000
Federal Government	212.9	193.3	1.101
Industry	207.1	214.2	0.967
Colleges & Universities	286.6	223.3	1.283
Other Nonprofit	201.4	172.1	1.171

Source: Derived from Table 1.

TABLE 4. ESTIMATED SOURCES OF FUNDS FOR INDUSTRIAL PERFORMANCE OF R&D BY BROAD INDUSTRIAL CLASSES, 1990

(Millions of Current Dollars)

	Federal Funds	Industry Funds	Total Funds	% Federal
Aerospace	17,388	6,876	24,264	71.66
Electrical Machinery & Communications	6,091	10,100	16,191	37.62
Machinery	1,894	13,066	14,960	12.66
Autos, Trucks & Parts, & Other Transportation Equipment	1,505	9,350	10,855	13.86
Chemicals	221	10,542	10,763	2.06
Professional & Scientific Instruments	661	3,580	4,241	15.59
Petroleum Products	19	1,859	1,878	1.01
Food & Beverage	0	1,523	1,523	0.00
Rubber Products	330	1,102	1,432	23.08
Fabricated Metals	121	1,101	1,222	9.91
Stone, Clay & Glass	50	1,090	1,140	4.39
Other Manufacturing	15	960	975	1.54
Pulp & Paper	0	684	684	0.00
Iron & Steel	0	620	620	0.00
Nonferrous Metals	20	329	349	5.66
Textiles	0	259	259	0.00
Total Manufacturing	28,316	63,040	91,356	31.00
Non-Manufacturing	5,543	3,167	8,710	63.64
TOTAL	33,859	66,207	100,066	33.84

NSF surveys—generally considered to be the most reliable—suffer from a lack of updating of the samples taken. In the past few years, NSF has made a major change in the sampling procedure. As a result, their most recent results (yet unpublished) reveal that there has been a significant change in the reported amounts of R&D performance. In part, the discrepancies between the published and to-be-published data relate to the fact that a large number of new companies have been formed within the past few years, and that mergers and acquisitions have had some impact on the total performance. It is expected that future estimates and forecasts of industrial performance will be affected to a considerable degree by this change in sampling and coverage.

In spite of the uncertainties that attend the actual numbers that are reported or projected, it is important to emphasize that the *trends* in R&D performance and the factors that influence these trends are more important than the more accurate figures.

The performance of R&D by industry will be financed either by the federal government or by industry itself (Tables 2 and 4). Industrially funded work will mostly be done by industry either internally or contracted out to other industries. A very small amount (approximately 2 percent) will be done extramurally by universities and other nonprofit institutions. The nonmanufacturing industries perform relatively little R&D but, as noted in Table 4, approximately 64 percent of the support for this activity is provided by the federal government. In contrast, R&D is more heavily self-funded by (and in) the manufacturing industries where, on the average, about 31 percent of the total performance is supported by federal funds.

The leading industry in the nation for R&D will again be the aerospace industry, projected to spend approximately $24.3 billion, with almost three-fourths of its funds coming from federal sources. In second place will be the electrical machinery and communications industry, projected to spend $16.2 billion, of which 37.8 percent is federally funded. Since 1980, these two major sectors have dominated and interchanged between first and second place. Further appropriations for defense systems, as well as anticipated growth in the computer and communications industries, are expected to continue the dominance of these two broad industrial classes.*

*Note here, for example, that two of the major aerospace and electronics contractors—EDS and Hughes Aircraft—are not represented in these compilations or estimates. Acquisitions have resulted in these companies' R&D efforts now being incorporated into other industries' totals.

Aside from aerospace, where federal support of R&D is dominant, there are no industry groups in which more than half of the R&D performance is expected to be directly supported by federal grants and contracts. In addition to electrical machinery, communication, and the rubber industry, no other industries are expected to receive as much as 16 percent of their funding from federal sources.

Finally, we call attention to the fact that the total industry funding shown in the third column of Table 4 makes no distinction between R&D performed in-house and that contracted out to other industrial firms.

Factors Affecting Future Industrial Support

Over the past few years, industrial spending on R&D has increased significantly although, as anticipated in recent years' Forecasts, the rate of increase in 1990 will be slightly lower. Recent spurts in industrial support had been the result of a healthier economy, increased sales and profits (both early indicators of R&D fund availability), relaxation of perceived barriers to cooperative research, and—to a small degree—the R&D tax credit enacted in 1981. However, other factors have influenced the present near-future support for R&D. As one looks at these factors there are several points which must be emphasized, especially if we are to appreciate the lessons of history and plans for the future.

Industry is not driven solely by technology and its availability, nor should it be. The U.S. R&D enterprise has, over the past 30 years and more, provided an incalculable wealth of understanding, a veritable flood of knowledge related to the properties of materials and the devices and systems that can be developed from them. Almost every sector of the economy has developed a backlog of information and know-how that can continuously enhance all manner of processes and products. It is well within our grasp to improve health care; to access, process, and utilize growing volumes of information; to implement processes and products that would in the long run save all manner of resources; to improve the capacity for growing, processing, and distributing food products; to reduce pollution and take advantage of waste; and to bolster the overall physical infrastructure.

But the availability of technology and the fruits of R&D do not determine the extent to which technology is applied. The use of new technology can carry significant cost—including the direct cost of acquiring know-how, and the unamortized costs of in-place processes. Moreover, applicable long-term debt service adds another element in the decision to adopt new processes or approaches. The ultimate resolution then comes down to a series of alternatives and considerations: to adapt or not; the cost of innovating as contrasted with the cost of *not* innovating; and the issue of potential short-term losses vs. long-term profitability or even survival.

With these considerations as background, it is now appropriate to note several points that have had an impact on recent industrial support of R&D, and which are expected to affect the near-term future support.

The philosophical cheerleading which emphasized "reindustrialization" and "competitiveness" may have driven selected firms to make the necessary investments to modernize operations and increase productivity. But other forces have had their influences on industrial R&D expenditures. Specifically, the commitment to long-term growth and strength has been affected by significant return to the short-term outlook that pervaded industrial management only a few years ago. The concepts of research and innovation are basically incompatible with the near-term profit objective. Thus, much effort has been directed toward alternative means of achieving this end, namely, the continued restructuring, buying of companies, and selling of nonrevenue producing components, and "the art of the deal". Manipulation, rather than innovation, has become the route to selective success.

The merger and acquisition practice has had some impact on R&D funding, and this is manifest in at least four ways: (1) the reduction or elimination of R&D spending and facilities, while aiming for short-term profit; (2) the use of resources to pay off debt incurred by acquisition; (3) the defensive approach of buying back stock to fight takeover attempts; and (4) the reduction of duplicate operations in intra-industry mergers. The last factor represents a reduction in total funding without a significant loss of technology-development potential. The first three are obviously detrimental to technical growth.

Industrial support of R&D usually lags decision-making by one to two years. Funding in 1990 will thus be influenced by events and uncertainties that were evident in 1988 and 1989. The major readjustment of the stock market and the mere thought of a changing administration were partially responsible for the reduced rate of growth of R&D spending.

For the past two years, this Forecast has expected such a slowdown, perhaps even resulting in *decreases* in the constant dollar support of R&D. Such decreases certainly would not be unprecedented, there having been a similar reduction in the early and mid 1970s (see Figure 3). If such a turnaround were to come, it would probably not last long;

barring unforeseen major dislocations in the economy, a renewed perception of a federal government that is "friendly" to business will mostly reinstate confidence and the resultant support to R&D.

A final word on the effects of mergers and acquisitions carries more of a warning than a forecast. In those cases where acquisitions result in significant debts, there is concern that debt service—which has present-day obligations—would consume revenues that might normally have been directed to research (with the concomitant longer-term payoff). The consequent reduction of resources used to obtain a technological advantage—through either direct R&D or direct purchase of technology—will then have adverse effects upon competitive position and survival. In times of tight budgets, R&D might be considered a "deferrable luxury," yet, the ever-changing and advancing nature of technology is such that opportunities deferred can quickly become alternatives lost.

In looking toward the longer-term impacts of present-day change, it is tempting to consider the effects of international affairs on the health of U.S. business and the implications for R&D. Two major events—one planned and the other totally unpredicted—can affect U.S. industry over the next few years. The anticipated European coalition, which will reach a milestone with the 1992 relaxation of intra-EEC barriers, will create a market that is presumably characterized by uniformity in trade, access, standards, and other factors. The truly "common" Common Market presumably offers opportunities for expanded markets and sales, which would generally have a positive impact on R&D.

The other element—the restructuring of the political and economic climate in Eastern Europe—creates an image of greatly expanded markets. This event, coupled with the impact on U.S. defense policy and procurement and the strains on the federal budget, conjures up a picture of a restructuring of U.S. industry and the response to a huge pent-up demand for non-military hardware and technology. The combined situation might suggest vastly increased readjustment of U.S. industry (with the associated expansion in R&D) in response to a new market opportunity. At the same time, one must be cautious in taking this argument too far. The "de-militarization" of the U.S. economy is different from that which occurred in the late 1940s: the present new demand is not backed up by an availability of hard currency which is sufficient to bring the new market to a reality in the short term. If convertible currencies *are* developed, U.S. (and EEC) markets may well be expanded, and the U.S. industrial investment in the necessary R&D (e.g., manufacturing modernization, customized products for foreign users, materials and methods for infrastructure development, and the like) may exhibit marked increases.

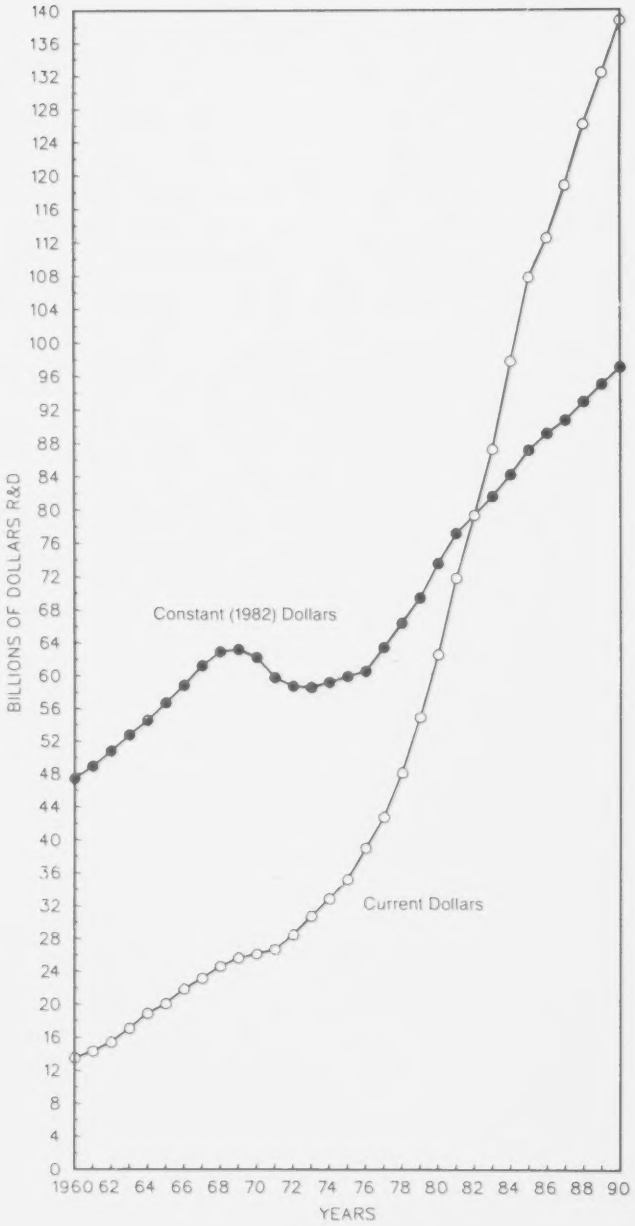


FIGURE 3. TOTAL R&D EXPENDITURES, 1960-1990, IN CURRENT DOLLARS AND CONSTANT DOLLARS (1982 = 100%)

The Role of Academic and Other Nonprofit Institutions

Nonprofit institutions—colleges, universities, and other types—both fund their own research and conduct research funded by federal agencies and/or industrial firms. It is generally conceded that a significant portion of all basic

research as well as some of the longer maturing applied research, is conducted in this sector.

In 1960, the academic and other nonprofit institutions financed from their own resources (including endowments and direct state and local funds) approximately 2 percent of all R&D (see Table 1), while actually performing over 9.5 percent of the total. For 1990, Battelle forecasts that these same nonprofits will provid 4.27 percent of all funding and will perform almost 17 percent of the total (see Table 2). These percentages are slightly higher than the corresponding ratios for the 1989 NSF estimates.

The growth in nonprofit R&D performance has been accompanied by minor shifting within the nonprofit sector. In 1960, the academic community accounted for 55.4 percent of total nonprofit funding and performed 78.1 percent of the nonprofit total. For 1990, Battelle forecasts 68.6 percent and 84.2 percent, respectively. A significant portion of the increase in academic support and performance derives from the increase in major industrial support ("directed endowments") associated with specialized areas of research such as electronics, artificial intelligence, and biological sciences.

There are two distinct groups of "other" nonprofit organizations. These are the foundations and associations which exist for various charitable and other purposes, and the nonprofit research centers which may or may not perform under contract. The first group funds a great deal of research, through grants and contracts. These go both to members of the academic community and to other nonprofit centers. The second group acts in three ways: (1) a member may perform as a foundation; (2) it may fund its own research performance; and/or (3) it may perform under contracts (with government, industry, or other nonprofits).

From 1965 to 1980 other nonprofit performance has fluctuated slightly between 3.3 and 3.7 percent of total R&D. Since then, this sector has declined to less than 3 percent. For 1990, Battelle estimates that the other nonprofit sector will comprise 2.67 percent of total R&D performance. Furthermore, we estimate that 52.8 percent of other nonprofit funding will go to colleges and universities, with the remaining 47.2 percent being spent by the other nonprofit sector itself. Following a decline in the 1976–1981 period, the percentage of support to colleges and universities is slightly higher than in recent years.*

*We must be cautious in drawing conclusions from the available data on R&D in the university and other nonprofit sectors. The primary survey data from which we work have not been collected directly and in great detail for a number of years. The NSF data are fairly good estimates, but small differences can give rise to significant percentage errors.

The total R&D performance in the other nonprofit sectors is not increasing as rapidly as in other performing sectors. However, as noted above, this sector is composed of quite diverse constituent organizations. As performers of R&D, the establishments within this sector range from institutions such as Battelle (engaged in a spectrum of technology development, commercialization, and management programs) to small nonprofit firms that act as delivery mechanisms and research arms for federal, state, or local government agencies, especially for social programs. The activities of these latter types of organizations have been significantly reduced in recent years. As might be expected, the extent to which agencies support research is roughly related to the magnitude of their operational programs.

With large proportional decreases in, for example, federal funding of social programs, the concomitant decrease in research related to these programs has been felt by many nonprofit research organizations. Hence, it is not unexpected that the aggregate of nonprofit performers should display smaller-than-average growth rates, or, in fact, real declines in comparison with other performing sectors.

Finally, in addition to contracts or grants to support research on industrial problems (the "industry funding of colleges and universities" shown in Table 2), there is another form of support, not yet reported in detail by the NSF, that must be noted. This is the industry/university arrangement which takes a form that more nearly resembles "directed endowments" than either a specific research contract or a general gift. The large multiyear programmatic grants are then accounted for as college and university self-funding.

R&D in the nonprofit sectors—particularly the colleges and universities—has been one of the mainstays of the growth of that basic knowledge that had led to the development of the total economy. In both public and private institutions, R&D has served both to expand understanding of science and technology and to play a critical role in the education process itself. Unfortunately, there is no totally reliable estimate of the amount of R&D that is actually conducted, or the relationship between the funding agencies and the performing institutions. Thus, one cannot develop reliable rationales or policies which relate to academic research, its support, and its important role in further advancing the objectives of an industrialized, technolo[illegible]-based society. As greater emphasis is placed on the issues of competitiveness and the most efficient use of total technical resources, a greater effort should be directed toward understanding the role that university research plays in the national economy and the incentives and barriers which influence utilization of this resource.

The Cost of R&D Inputs

From an economic point of view, inflation can be defined as a general rise in the price of goods and services that is not offset by corresponding increases in quality. If the prices of everything tend to rise together, slowly and in the same proportions, and if individual incomes also rise in those same proportions, the relationship between money and goods/services changes in a fashion which is detrimental mainly to the holders of such fixed-dollar obligations as life insurance. On the other hand, when the prices of things bought with income rise faster than the incomes, structural imbalances occur which may be quite painful to particular sectors of the economy.

Goods Versus Services

Most considerations of prices tend to take place within the context of goods' prices (i.e., the prices of tangible things). The tangibility of goods makes it possible both to measure the quantity of their output and to estimate, within reasonable limits, changes in their quality. Thus, with respect to goods, there usually is agreement as to whether or not costs are rising faster than output, or prices faster than quality. That is to say, we tend to have general agreement that inflation is or is not occurring in the goods-related economy.

Services, on the other hand, are intangible. Therefore, we usually have greater difficulty achieving agreement that, in terms of any meaningful measure, the quantity or quality of service output is rising or falling. Thus, our only measure of many types of service output is the total amount of money that we pay for them—and that is a function of price and quantity, with no account taken of quality.

R&D, by definition a part of the "knowledge industry", is primarily a service activity, despite the fact that much of it ultimately becomes embodied in products. For this reason, we have no agreement as to what can be termed a "unit" of R&D output. Therefore, we cannot ascertain whether or not the "price" of R&D output is rising or falling. However, we can put a price on R&D inputs. For that reason, most discussions of the cost of R&D tend to be couched in those terms. Battelle has not yet given up hope of achieving a measurement of R&D output and from time to time has undertaken investigations which may lead to quantifying at least some kinds of R&D output. Nevertheless, such a measurement is not now available and the discussion which follows must be in terms of input costs.

In viewing the costs of R&D performance, it is tempting to contrast the "inflation" in R&D with the commonly used Consumer Price Index—the factor which provides a measure of general inflation—or to use the Gross National Product (GNP) deflator, as NSF does. To do so misses three basic points distinguishing R&D from the more general set of purchases. First, the CPI is based upon a defined average "marketbasket" purchased for general consumption, and the GNP deflator covers a somewhat broader range. However, purchases by R&D performers are from a much more specialized collection of goods and services.

Second, the education of scientists and engineers has a built-in bias for the acquisition and use of more sophisticated (and, hence, generally more expensive) materials, devices, and systems required for the conduct of research. Were it not for this factor of the research culture, technological advancement would not be so rapid.

Third, and perhaps most important, the very nature of research is such that the problems addressed by researchers are increasingly more difficult. The easy questions are always answered first, and the effort necessary to make incremental gains in the understanding and application of science and technology is ever-increasing. Thus, we generally expect that the "inflation rate", as applied to the conduct of R&D, will increase more rapidly than that of the average consumer purchases.

The Cost of Research Index does not *always* exceed the GNP deflator or the Consumer Price Index. While it is based upon the average weighted expenditures of R&D dollars per R&D professional, one must note that the actual dollars support a broad range of technical support personnel, computer hardware and software acquisition and use, amortization of equipment, and all the overheads associated with the conduct of research. Thus, the Index is also related to the sophistication of support equipment and the total environment of the research laboratory. Furthermore, there is an expected difference in the Index as it is interpreted for Basic and Applied Research, and for Development. To date, no effort has been directed toward analyzing the distinction between these broad fields of research, and no detailed methodology has yet been devised for investigating the true costs of research in greater detail.

The "Cost of R&D Input" Index

In the absence of a measure of R&D output costs, many organizations, including the NSF, use the GNP deflator (from the national income and product accounts) as an indicator of changes in R&D costs. This index responds to the costs of both goods and services. R&D costs are made up primarily of service costs. Battelle researchers, therefore, feel that the GNP deflators probably have misstated rates of inflation with respect to R&D.

Several attempts have been made to determine the input mixes of typical R&D activities and to price each input, thereby generating standard weighted price indexes for R&D. To date, this approach has not been very productive, although such efforts continue and may eventually achieve success.

A pioneering effort to more directly measure trends and fluctuations in the cost of R&D was made by Helen Milton beginning in 1966.* Using information supplied by representative R&D performers, Milton compiled data on the total dollar cost of R&D per technical (professional) man-year.** Her series of cost indexes ended with 1970, using 1950 as the base year. Between 1970 and 1979 Battelle extended the Milton Index Series by means of annual estimates. Finally a new series of R&D cost indexes was introduced in the 1980 Battelle Forecast and Analysis. This new series, while conceptually similar to the Milton Series, is based upon a different body of data and does not show precisely the same year-to-year changes as the Milton Series and our earlier extensions of it.

The Battelle Cost of Research Index, displayed in Table 5, is based upon two series regularly published by the NSF: (1) the R&D performance figures, by sectors, that have already been discussed in connection with the Source/Performer Matrix (Table 2); and (2) estimates of the full-time equivalent numbers of R&D scientists and engineers employed by each performing sector. The ratio of costs to scientists/engineers for each sector provides the basis for the sectoral subseries, which are then weighted and combined into the all-sector average.

As derived from Table 5, Battelle's best estimates of recent increases in the total index are 3.7 percent for 1986–88, and 2.6 percent for 1988–89. We expect the cost of R&D to increase by about 2.6 percent between the estimated 1989 level (139.24) and the forecast level for 1990 (142.85) with the estimates stated in terms of the 1982 base.

Sector Comparisons of R&D Costs

During the interval 1982-90, costs of all R&D, as an average, are estimated to have risen by 42.9 percent. Increases in the individual performing sectors are expected to be: federal government, 61.3 percent; industry, 39.1 percent; colleges and universities, 52.9 percent; and other nonprofit, 30.9 percent. As noted, the 1989-90 cost increase for all R&D is estimated to be 2.6 percent. By sectors, the increases are estimated as federal, 3.3 percent; industry, 2.5 percent; colleges and universities, 3.1 percent; and other nonprofits, 0.7 percent.*

Trends in Real R&D Effort, by Sectors

If we take total expenditures and sector performance figures from Tables 1 and 2 and deflate them to constant 1982 dollars with the corresponding index numbers from Table 5, we can make parallel comparisons for each of the four performing sectors. These are shown in Table 6 and graphed in Figures 3 and 4.

In current (undeflated) dollars, total U.S. R&D expenditures have risen in every year of the period, even though the rate of increase fell sharply between 1969 and 1971. But the deflated (real effort) series before 1978 reached its peak in 1969, declined between 1969 and 1973, and moved generally sideways until 1977, when it exceeded $62 billion for the first time in eight years. We expect real R&D effort in 1990 to increase by 2.13 percent over 1989 and to reach a level that is 53.6 percent above its 1969 peak.

When we shift our attention to the performing sectors, we find that the recent upward drift of real R&D activity results from the behavior of the private sectors. The downturn or flat behavior in real expenditures that began after 1968–69 is clearly reflected by every sector. However, deviations in sector behavior emerged later, especially since about 1975. In government, the real performance series has recovered only slowly from its 1976 minimum and has not yet equaled its 1968 peak.

In the private sectors, industry reached its real low in 1972 and has since risen by 80.8 percent to its highest recorded value. The academic community reached a low in 1973. Since then, its real performance has risen by 73.5 percent and now stands well above the 1968 value. Other nonprofit institutions' real performance declined slightly from 1968 through 1970. Since that time, it has risen by 50.5 percent.

Finally, we turn to the data of Table 6 and the curves of Figures 3 and 4 to see the dramatic differences in the R&D trends among the four performing sectors. Since the lull of the early 1970s, industrial performance, funded by both government and industry, has been largely responsible for the real growth within the R&D enterprise. Using the same performance deflators as applied to the sources of funds, over the past decade, industrial support of R&D

*See Helen C. Milton, "Cost of Research Index, 1920–1970", *Operations Research*, 20, 1–18 (1972).

**Milton said that "The 'technical man' is the professional scientist or engineer, plus his support".

*The estimates of the Cost of Research Index and its year-to-year change are quite sensitive to changes in the basic data on expenditures and employment levels. Much of the input data are derived from NSF resources which, as noted earlier, are adjusted annually.

TABLE 5. BATTELLE COST OF RESEARCH INDEX* BY PERFORMING SECTORS, CALENDAR YEARS 1960–1990 (1982 = 100)

		Performing Sectors			
Year	Total U.S.	Federal Government	Industry	Colleges and Universities	Other Nonprofit
1960	28.54	23.03	30.76	20.42	35.28
1961	29.28	24.07	31.11	23.25	36.21
1962	30.33	25.64	31.78	26.02	37.50
1963	32.35	26.48	34.05	28.89	37.04
1964	34.57	31.57	35.57	32.21	36.50
1965	35.34	32.85	36.23	33.09	37.09
1966	37.12	33.02	38.43	34.60	39.24
1967	37.80	33.52	39.08	35.77	39.93
1968	39.09	33.68	40.61	37.95	39.07
1969	40.56	34.58	42.24	37.71	45.69
1970	41.99	39.67	42.80	39.22	48.11
1971	44.61	43.43	45.45	41.11	47.01
1972	48.46	49.07	49.14	44.14	48.62
1973	52.41	53.71	52.68	49.95	50.23
1974	55.47	55.29	56.30	51.05	56.29
1975	58.74	60.18	59.14	54.35	61.77
1976	64.41	71.04	64.29	58.36	65.19
1977	67.44	71.75	67.42	62.87	69.36
1978	72.49	78.29	71.54	71.29	74.46
1979	79.09	84.82	77.77	80.23	80.73
1980	85.07	85.49	84.39	87.92	87.05
1981	93.06	93.41	92.42	96.04	94.85
1982	100.00	100.00	100.00	100.00	100.00
1983	106.91	113.31	105.78	107.36	108.30
1984	116.08	122.31	115.11	115.25	119.69
1985	123.59	135.09	121.81	123.58	125.30
1986	126.15	140.35	122.88	132.58	127.95
1987	130.86	141.32	127.90	138.78	133.05
1988	135.67	153.26	132.15	143.58	128.18
1989	139.24	156.16	135.74	148.25	129.96
1990	142.85	161.32	139.11	152.90	130.89

*Costs of performing R&D per scientist/engineer (full-time equivalence).
Source: Estimated by Battelle from NSF and Battelle data.

has increased at an average compounded rate of 2.89 percent per year, while federal support has increased at 1.57 percent per year on average.

The behavior exhibited in Figures 3 and 4 suggests that the real growth in R&D (and the economic development and expansion that result from it) has come from the applied research supported and performed by private industry. However, one cannot overlook the fact that such applied research and development must rest on, and evolve from, the basic research foundation—an activity that is primarily supported by the federal government (almost 65 percent).

Over the past few years, federal support has tended to shift more toward "development" and less toward basic and applied "research".* The federal government is still the major supporter of basic research, and trends in the federal budget indicate that this support will continue to be strong. In addition, there is a continuation of basic

*One must be careful not to read too much into the data which are available regarding the divisions among basic and applied research, and development. It is at times difficult to make the distinction as to where one phase stops and the next takes over. Furthermore, the definition as applied by the supporter may be substantially different from that applied by the performer.

research support by industry. Yet, the volatility of those indicators (sales, profits, cash flow) which influence industrial R&D budgets precludes the stability needed for long-term planning. Policy- and budget-makers in all funding sectors should note very carefully the trends in basic research, since the conduct of such research forms the basis for future economic vitality and competitiveness.

Thus, the federal government, in any attempt to maintain the vitality of our technology-based and technology-influenced economy, should continually reexamine its policies relative to (1) the support of R&D, (2) the roles of the public and private sectors, (3) the factors which enhance or impede the progress of science and technology, and (4) the commitment to science education at all levels.

A Look Toward 1991 and Beyond

While former issues of the Battelle Forecast and Analysis (through the 1983 edition) had been confined to considerations of the forthcoming year only, well-established commitments by both the federal government and industry generally have permitted a longer look at the R&D forecast. Judging from recent trends in government spending, long-term budget commitments (tempered by budget-cutting activities), and the existing overall business climate, it is estimated that 1991 sources for R&D will be:

Federal government	$ 66,600 million
Private industry	70,640 million
Colleges & universities	4,340 million
Other nonprofit organizations	1,920 million
TOTAL	$143,500 million

In addition, it is estimated that 1991 expenditures of R&D will be distributed among the four performing sectors as follows:

Federal government	$ 15,360 million
Private industry	104,090 million
Colleges & universities	20,330 million
Other nonprofit organizations	3,720 million

The overall 3.5 percent increase in funding and performance (expressed in constant 1990 dollars) will be unevenly spread among funding and performing sectors. It is expected that both funding and performance by the federal government will increase more slowly than average, while all other sectors' funding and performance will increase more rapidly.

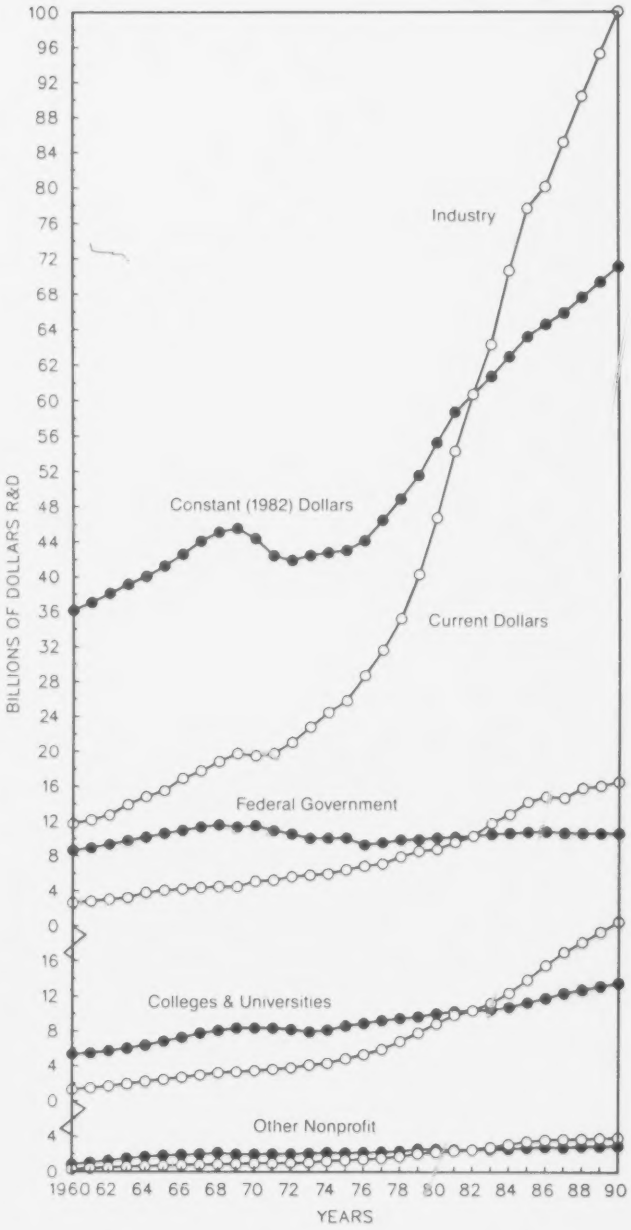


FIGURE 4. R&D EXPENDITURES BY SECTORS, 1960-1990, IN CURRENT DOLLARS AND CONSTANT DOLLARS (1982 = 100%)

The trends which pointed to a slowdown in the rate of growth, noted in the last two years' Forecasts, are expected to continue. While federal funding of R&D had increased substantially—largely influenced by defense programs—the growing federal deficit was beginning to take its toll. It was inevitable that new, and perhaps unpopular,

actions would be required. To a significant degree, the Gramm-Rudman-Hollings Act has forced reductions in the rate of growth of expenditures. In addition, the "peace dividend" will have some effect on the growth of both total DoD expenditures and R&D. The magnitude of this dividend is yet to be hammered out, for there are many political interests which have to be satisfied and compromised. We expect that the rate of growth will continue to slow, although some real growth in federal spending will occur.

The picture regarding industrial R&D growth is a little more difficult to decipher, since other kinds of forces have an influence. Federal policies certainly affect industrial decision-making. Action or inaction relative to increased private and corporate taxes, limited import duties or other protectionist measures, R&D tax credits, patent policy, actions relative to mergers and acquisitions and cooperative research will continue to affect industrial commitment to R&D, as they have in the past. These generally act more as small perturbations on the more important driving forces for industrial support of research and development, namely, (1) the need to respond to competition (both foreign and domestic) and (2) the availability of funds from earlier years' sales and profits.

One bright light as regards both government and industrial funding is the acceleration of interest in technology transfer and adaptation as more federal laboratories take a stronger interest in promoting their own technical capabilities. Additional funding from providers and users—perhaps through intermediary channels—will likely be forthcoming.

Increases in university self-funding and performance in the near future continue to be, in part, a consequence of increased industrial actions of the recent past. The relaxation of apparent barriers to industrial cooperation created a funding mechanism which has infused substantial additional resources to the college and university sector. Counted as the sector's "own funds", this form of R&D support and performance will most likely continue to grow slightly over the next few years. However, it is also quite possible that a period of disenchantment will set in, particularly if any of three factors comes into play: (1) if the universities feel an encroachment upon their independence and sovereignty; (2) if supporting industries are unable or unwilling to reduce research to applications and profit; or (3) if sales and profit figures for industry are such as to reduce future "endowed investments" of this type. If any of these conditions comes to pass—and the next two to three years is the critical period—the industry/academia honeymoon may be merely an anomaly in the broader picture of long-term relations.

The national commitment to continued support and growth of R&D is based upon the observation of the positive impacts of past actions. Each funding and performing sector—individually and in concert with the others—has made major contributions to the economic strength and security of the nation. Furthermore, this cooperative effort has permitted the assumption of a pre-eminent position among the nations of the world.

But as technological advances are made, a greater effort should be pursued to look at the long-term implications of R&D. There are many difficult questions that must be addressed, including considerations of the educational system, the potential displacement of skilled and unskilled laborers, the impacts of increased life expectancy, and the general changes in the delivery of goods and services. Government and business alike have a responsibility to take the longer view, to assess the impacts of technological change, and to develop alternative postures that can assure that the benefits of technological change can be realized without serious disruption to the society.

In all of the discussion which relates to both the short- and long-term projections for R&D, we should reiterate two major themes that have permeated this year's Battelle Forecast:

(1) Government actions relative to the budget and their long-term effects on R&D funding, and
(2) The industrial response to financial, not economic, concerns as reflected by the vagaries of the stock market, the predilection toward takeovers and mergers, and the return to more of the short-term, bottom-line rationale which governed earlier behavior.

The Need for Better Data

Industrial Line-of-Business R&D

Over the past several months, the theme of "competitiveness" continued its popularity. Along with "restructuring", "reindustrialization", and "infrastructure", this theme is likely to dominate discussions related to trade, economic growth, and any "new horizons" which will characterize the stand of the new administration. We do not expect the concept to be merely a popular buzzword, for it carries significance which was of concern long before the popularization of the word itself.

Earlier, we alluded to the difficulties associated with attempts to analyze industrial expenditures on R&D. The most readily available statistics—including those from the

NSF surveys, the McGraw-Hill surveys, and the SEC 10-K forms—make no distinctions among R&D commitments to various lines of business. Chemicals research conducted by companies in the petroleum industry is not reflected in the statistics which refer to the broad industrial class of "Chemicals". Conversely, petroleum-related research conducted by the chemical companies is not included in figures which presumably represent "petroleum research". As automotive companies devote significant funds to electronics and computer research, as tobacco companies acquire food processing and distribution concerns, and as both inter- and intra-industry mergers or acquisitions occur, there is continued erosion of our understanding of the distribution of R&D and the factors which influence trends.

Industry R&D managers have long felt the need for more detailed information as it applies to their own commitments to R&D, the distribution of limited resources (both dollars and personnel), and the optimization of the R&D operation. The information needs include not just a compilation of their own efforts, but also a comparison between their own statistics and those which represent the industry as a whole. Without more detailed information regarding the trends among critical ratios in the various lines of business for which an R&D manager is responsible, the decision-making process is impaired.

As a result of this need, and recognizing the risks involved with individual attempts to gather data, Battelle has initiated projects which provide the type of analyses and comparative information that is an integral part of the resource management process. Starting with the petroleum industry, and expanding this to others, a procedure has been developed that addresses the basic information needs while avoiding the complications that would be faced by individual companies.

At the present stage of development, the approach provides line-of-business detail on relative expenditures and personnel levels devoted to R&D, technical services, and technician support; leading and lagging relations between R&D and sales, earnings and capital expenditures; and correlations between the R&D indicators and other measures of company activity, including materials or finished product throughput.

These are the types of data which assist individual companies in improving their own competitive position, in setting internal R&D policy, and in providing the input necessary to integrate R&D with the larger strategic planning and analysis process.

The expansion of the approach to other industries, including chemicals, automotive, paper and wood products, ceramics, pharmaceuticals, information processing (including hardware, software, peripherals, etc.), composites, polymers, and the like, is expected to provide a better picture of the trends within R&D and a more nearly accurate accounting of the distribution of R&D effort. In addition, extension of the study to include both U.S. and foreign R&D efforts will give a truer picture of the competitive position of U.S. industry.

The basic nature of the program is such that the outputs of these surveys and analyses are generally proprietary, and information has thus far been provided only to the participating companies. To the extent that broad average values and trends can, by agreement with the participants, be made available, selected data will be included in future issues of the Battelle Forecast.

International Comparability

While intra-industry comparability is useful for assisting individual companies to analyze their competitive position and develop R&D strategies to meet future markets, international comparability is often sought as a means of determining whether total U.S. efforts will result in maintaining a preferred position relative to future trade and economic strength. Broad statistics on total R&D, selected comparisons on R&D in various functional areas, and estimates of R&D as a ratio to GNP or equivalent are usually available through the National Science Foundation, the Organization for Economic Cooperation and Development (OECD), and other agencies.

The numbers that describe total U.S. and foreign R&D efforts are instructive to the extent that they permit general assessment of the relative commitment to R&D and some insights into the distribution of total R&D resources among various functional areas. However, these types of data are of relatively little value when attempting to formulate policies or approaches that must be translated into specific actions. The total value of R&D investment provides no more detail on the national scale than does the total value of R&D as reflected in the industrial R&D quoted in the sources cited in the previous section. That is, total values tell you everything, while telling you nothing. They provide gross statements relative to national expenditures, but they say nothing about the structure of the R&D effort, the relationships among supporting and performing sectors, and the manner in which these relationships change as a result of policy actions.

In its simplest structure, the U.S. data, as presented by NSF and Battelle, consider the four major source/performer sectors of federal government, industry, colleges

and universities, and other nonprofit organizations. Support for the Federally Funded Research and Development Centers (FFRDCs) is usually separated only for those FFRDCs managed by colleges and universities, while that for FFRDCs managed by industry or nonprofit organizations is generally absorbed into the total values which represent these sectors. Furthermore, as has been noted earlier, the R&D support provided by subnational units of government (such as direct support to the state universities) or through endowments or other gifts to R&D-performing institutions is not isolated, but is absorbed under the category of "own funds".

Although the situation is not perfect elsewhere, Battelle's preliminary analyses have shown that other countries' statistical efforts are more disaggregated. They permit inspection of more detailed relationships between the various classes of supporters and performers of R&D, and—taken to the most logical conclusion—they provide the background tools that are necessary for sensible policy development and evaluation. For example, nowhere in the U.S. collection of R&D statistics is there a continuing measure of the interactions between industry (as a supporter of R&D) and the federal laboratories (as a performer); the industry/federal cell of Table 2 is *defined* as being empty, while it is known that a nonzero entry should be made. Thus, there is no well-defined measure of the extent to which the Stevenson-Wydler Act and the subsequent Technology Transfer Acts of various years have been effective in promoting this interaction.

Furthermore, there is no isolation of the contributions made by state governments to the general conduct of R&D in the state universities, or the specific R&D projects done on behalf of state government. And as a final example, there is no continuing data base that provides insights into the distribution of industrially-supported R&D into cooperative programs or the separation between industry-funded work that is carried out in an industry's own laboratories as compared with that carried out in other industries' facilities.

While not all of the detail available in other countries' data may be necessary for the U.S. setting, it is obvious that the U.S. statistics provide only limited value relative to policy development. As the issue of competitiveness continues to be raised in political rhetoric, industrial policy, and trade discussions, and as concern for long-term economic strength transcends mere political expediency, efforts should be directed toward improved understanding of the relative position of the U.S. R&D enterprise and toward assuring that the policy debate takes place in an environment of knowledge. Furthermore, efforts should be made to learn the lessons of history as they apply to the future.

SPECIAL NOTE ADDED IN PRESS

Very recent sampling changes and re-estimations by NSF have had significant impacts on their reporting of R&D performance by industry. The new sampling procedures were developed to take into account the large number of companies that have been formed in recent years, and have resulted in there being identified nearly $10 billion in performance that would have been "missed" were it not for the new sample design. This major adjustment has had a significant effect on the total numbers that have been reported in this forecast. However, it is especially important to note that the *trends* in R&D expenditures are more important than the actual numbers. Nothing in the new NSF estimates changes the interpretation of data as presented in this report.

TECHNICAL APPENDIX

NSF DEFINITIONS OF RESEARCH AND DEVELOPMENT

Many activities, from one viewpoint or another, may be termed "Research and Development". The National Science Foundation (NSF) has, since its inception, been concerned with both the definition and the measurement of R&D. We probably can do no better than again quote the most recent definitions that the NSF has evolved. By these definitions, we can say:

"*Research and development* . . . consist of basic and applied research in the sciences (including medical sciences) and in engineering and activities in development . . .

"*Research*, which encompasses both basic and applied, is systematic, intensive study directed toward fuller scientific knowledge of the subject studied.

"*Basic research.* For three of the sectors—federal government, universities and colleges, and other nonprofit institutions—the definition of basic research stresses that it is directed toward increases of knowledge in science with . . . a fuller knowledge of understanding of the subject under study, rather than a practical application thereof. To take account of an individual industrial company's commercial goals, the definition for the industry sector is modified to indicate that basic research projects represent . . . original investigations for the advancement of scientific knowledge . . . which do not have specific commercial objectives, although they may be in fields of present or potential interest to the reporting company.

"*Applied Research.* The following is the core definition in the NSF questionnaire sent to the universities and colleges: '*Applied research* is directed toward practical application of knowledge'. Here again, the definition for the industry survey takes account of the characteristics of industrial organizations: it covers '. . . research projects which represent investigations directed to discovery of new scientific knowledge and which have specific commercial objectives with respect to either products or processes'. By this definition, applied research in industry differs from basic research chiefly in terms of objectives of the reporting company.

"*Development.* The NSF survey concept of development may be summarized as '. . . the systematic use of scientific knowledge directed toward the production of useful materials, devices, systems or methods, including design and development of prototypes and processes'."*

* National Science Foundation, *National Patterns of R&D Resources*, 1953-78/79. NSF 78-313, p. 25.

Corporate headquarters are located in Columbus, Ohio

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